Method of Test
FIELD MOISTURE - DENSITY RELATIONSHIPS
DOTD Designation: TR 415 - 99
ENGLISH VERSION

METHOD A - DETERMINATION BY FAMILY OF CURVES

I. Scope

A. This method of test is designed to determine the relationship between the moisture content of soils or soil-aggregate mixtures with 60% or less siliceous aggregate by wet weight retained on the No. 4 sieve (raw or lime treated) and the resulting density when the material is compacted as specified in this procedure. The moisture-density relationship of the material is determined though the use of the Family of Moisture-Density Curves (Figure A-1) and a one-point proctor. This method is to be used as permitted by DOTD TR 418.

B. Reference Documents
   1. DOTD TR 418 - Moisture-Density Relationships
   2. DOTD TR 403 - Determination of Moisture Content
   3. AASHTO M 92 - Wire Cloth Sieves for Testing Purposes
   4. DOTD S 401 - Sampling Soils

II. Apparatus

A. **Mold**
   1. A cylindrical metal mold having a capacity of 1/30 ft^3 manufactured with an internal diameter of 4.000±0.016 in. and a height of 4.584±0.005 in. and with a detachable collar approximately 2.5 in. in height, which can be fastened firmly to a base plate.
   2. Molds are to be replaced when any diameter is more than 4.024 in. or the height is less than 4.550 in. at any point.

B. **Compactive device**
   1. Automatic Rammer
      a. A metal 5.50±0.05 lb rammer, with a sector striking face that has an area equal to that of 2 in. diameter face for use with a 4 in. inside diameter mold and arranged to control the height of drop to 12.0±0.06 in.
      b. Alternate - a metal 5.50±0.05 lb rammer, with a sector striking face that has an area equal to that of a 2 in. diameter face for use with a 4 in. inside diameter mold and arranged to control the height of drop to 18.00±0.06 in.
   2. Manual Rammer - a metal 5.50±0.05 lb rammer with a circular striking face with a diameter of 2.00±0.01 in. and arranged to control the height of drop to 12.00±0.06 in.

C. **Compaction block** - a stable block or pedestal composed of portland cement concrete with a smooth, level surface on the top and bottom, with both surfaces parallel, weighing a minimum of 200 lb. The compaction block may be obtained from the district laboratory.

D. **Straightedge** - steel straightedge, approximately 12 in. long.

E. **Balance or scale** - a balance or scale having a capacity of 30 lb or more and sensitive to 0.01 lb.

F. **Sieve** - a No. 4 sieve conforming to AASHTO M 92.

G. **Tools**
   1. **Mixing pans** - with appropriate covers.
   2. **Spoons**.
   3. **Pointed trowel**.
   4. **Spatula** - or large suitable mechanical device for thoroughly mixing the soil with water.
   5. **Large screwdriver** - to remove material from mold.

H. **Water**

I. **Containers** - one-gallon friction top cans with tops.

J. **Density and Moisture Content Worksheet,** DOTD Form No. 03-22-0750. (Figure A-2)

III. Sample

Obtain, in accordance with DOTD S 401, a representative sample of the material in field condition, such that after preparation approximately 6 lb of material passing the No. 4 sieve is produced for each one-point proctor.

Note A-1: *If the sample contains aggregate, obtain approximately 15 lb for each one-point proctor.*

IV. Procedure

A. Determine the total wet weight of the sample(a) and record on the worksheet.

B. Screen total sample over the No. 4 sieve, forcing all material except aggregate through the sieve.

Note A-2: *If the aggregate retained on the No. 4 sieve is not siliceous, do not continue with this test method. Perform the test in accordance with the appropriate method of DOTD TR 418.*

C. Determine wet weight of the fraction retained on the No. 4 sieve (b) and record on the worksheet.

D. In accordance with step V. A., determine the percent retained on the No. 4 sieve based on the total wet weight of the sample (c) and record on the worksheet.

E. Compact the test specimen using the rammer, using material passing the No. 4 sieve at a moisture content that falls within the designated area on the Family of Curves.

1. If mold requires an attachable base plate, attach base plate. Determine the weight of the mold and base plate (e) and record on the worksheet.

Note A-3: *When using a mold without an attachable base plate, place wax paper on the compactor base. Weigh the mold and record the weight (e) on the worksheet. Place the mold over the wax paper and secure the mold to the compactor base.*

2. Attach the collar to the mold.
3. Thoroughly mix the material to be placed in the mold.
4. Place a quantity of the material in the mold in an even layer that will yield slightly more than 1/3 the volume of the mold after compaction.
5. Use a pointed trowel to rearrange particles, filling voids in the loose material without compacting the material, to a uniform lift thickness.
6. Rest the rammer on top of the layer to be compacted. Compact the layer using 25 blows with the 5.50 lb rammer from a 12 in.. drop (alternate 17 blows with a 5.50 lb rammer from an 18 in.. drop).
7. Note the height of the compacted material. If the compacted layer is not 1/3 the height of the mold, correct for any deviation by adjusting the quantity of material used for the subsequent layer.
8. Repeat steps IV. E. 4 - 7 for two more layers.

F. After the third layer has been compacted, place the mold, base plate (if applicable), and compacted specimen in a pan.

G. Tap the collar with the straightedge to loosen material bond and remove the collar from the mold, without twisting or causing shear stress to the molded specimen.

H. Note the height of the compacted test specimen.

1. If the compacted material is greater than 0.25 in. above the top of the mold, remix it with the original material and repeat the test.
2. If the compacted material is below the rim of the mold, remove all the material from the mold, remix it with the original material and repeat the test.

I. Keeping the mold, base plate (if applicable) and specimen in the pan, trim the specimen even with the top of the mold, using the straightedge. Fill any depressions formed during trimming with the trimmed material. After the depressions are filled, smooth the top of the cylinder with the straightedge even with the top of the mold.

J. Determine the weight of the mold, base plate (if applicable), and specimen (d) and record on the worksheet.

K. Determine the wet density of the specimen (g) in accordance with step V.B. Record on the worksheet.

L. Detach the base plate from the mold. Remove the specimen from the mold.

M. Take a representative portion from the center of the compacted specimen. Use the representative portion to determine the moisture content (k) in accordance with DOTD TR 403. Record on the worksheet. (The entire specimen may be dried to determine the moisture content, in lieu of using a representative portion.)

N. Determine the maximum dry density and optimum moisture of the material passing the No. 4 sieve.

1. Plot a point on the Family of Moisture Density Curves (Figure A-1) representing the intersection of a horizontal line representing the wet density and a vertical line projected from the moisture content.

2. The point plotted in Step N. 1 must fall within one of the shaded areas (zones) of the curves (either the major 1-41 section or the supplemental a-l section).
   a. If the point does not fall within one of these shaded areas, repeat steps A - M with fresh material at a different moisture content, repeating until the point falls within a shaded area.
   b. When the point falls within the shaded area of the major section (Curves 1 - 41), select and record the corresponding zone number. Then read the optimum moisture (om) and maximum dry density (pr) for that zone from the table at the upper right of the Family of Moisture Density Curves. Record these values on the worksheet. Use these values to determine the optimum moisture and maximum density of the total material in accordance with steps O and P.
   c. When the point falls within the shaded area of the supplemental section (curves a - l), increase the moisture content by at least 3% and repeat steps IV.A - M.
      (1) If the point plotted at the increased moisture content indicates that wet density remains the same or indicates a reduction in wet density, select the zone letter of the supplemental section corresponding to the original shaded area and determine dry density and optimum moisture in accordance with step N.2. b.
      (2) If the point plotted at the increased moisture content indicates an increase in wet density, repeat step IV.N. 2.a. until a point falls clearly in the shaded area of the major section (curves 1 - 41). Then select the zone number from the major section and deter-mine the dry density and optimum moisture in accordance with step N.

Note A-4: *When a point does not plot clearly on a curve, yet appears to fall within the supplemental section (Curves a - l), it may be necessary to use field tests to identify the type of soil and its moisture content. The supplemental section represents sandy soils. Wet sandy soils will plot on the wet side of the curves in the supplemental section and dry clayey soils will plot on the dry side of the curves in the major section.*

O. Determine the maximum dry density of the total material (PR) using one of the following methods and record on the worksheet.
   1. If the percent retained on the No. 4 sieve is below 5, record the maximum dry density determined in step N.
   2. If the percent retained on the No. 4 sieve falls in the range of 5 - 20, read or interpolate by standard methods the maximum dry density of the total material using Table 1.
   3. If the percent retained on the No. 4 sieve is greater than 20 and not greater than 60, determine the maximum dry density of the total material in accordance with step V.D.

P. Determine the optimum moisture of the total material (OM) by one of the following methods and record on the worksheet.
   1. If the percent retained on the No. 4 sieve is below 5, record the optimum moisture determined in step N as the optimum percent moisture.
   2. If the percent retained on the No. 4 sieve falls in the range of 5 - 60, determine the optimum moisture of the total material in accordance with step V.E.

Note A-5: *Calculate and record values to the same degree of accuracy shown in the example on the worksheet.*

V. Calculations

A. Calculate the percent retained on the No. 4 sieve (c), based on total wet weight of the sample, to the nearest 1% using the following formula.

$$c = \frac{100b}{a}$$

where:

b = wt of wet material ret. on No. 4 sieve, lb
a = total wt of sample, lb
100 = constant, converts decimal format to %

example:

a = 15.64 lb
b = 6.54 lb

$$c = \frac{100 \times 6.54}{15.64}$$

$$= \frac{654}{15.64}$$

$$= 41.8158$$

$$c = 42\ \%$$

B. Calculate the wet density of the specimen.

1. Calculate the wet weight of compacted soil (f) to the nearest 0.01 lb and record on the worksheet.

$$f = d - e$$

where:

d = wt of mold, base plate, & specimen, lb
e = wt of mold and base plate, lb

example:

d = 13.51 lb
e = 9.32 lb

$$f = 13.51 - 9.32$$

$$f = 4.19$$

2. Calculate the wet density of the specimen (g) to the nearest 0.1 lb/ft^3.

$$g = f \times 30$$

where:

f = wet wt of compacted soil, lb
30 = constant representing the reciprocal of the volume of the mold, ft^3

example:

f = 4.19 lb

$$g = 4.19 \times 30$$

$$g = 125.7$$

C. Calculate the moisture content of the specimen.

1. Calculate the weight of water (j) to the nearest 0.01 lb using the following formula:

$$j = h - i$$

where:
h = wt of wet soil, lb
i = wt of dry soil, lb

example:

h = 1.38 lb
i = 1.19 lb

$$j = 1.38 - 1.19$$

$$j = 0.19$$

2. Calculate the moisture content of the specimen (k) to the nearest 0.1 % using the following formula:

$$k = \frac{100 \times j}{i}$$

where:

j = wt of water, lb
i = wt of dry soil, lb

example:

j = 0.19 lb
i = 1.19 lb

$$k = \frac{100 \times 0.19}{1.19}$$

$$= \frac{19}{1.19}$$

$$= 15.9663$$

$$k = 16.0$$

D. Calculate the theoretical dry density for materials with siliceous gravel in the range of 20 - 60 percent retained on the No. 4 sieve (PR) to the nearest 0.1 using the following formula:

$$PR = \frac{160(pr)z}{\frac{c}{100}(pr)z + 160\left(1 - \frac{c}{100}\right)}$$

where:

pr = max. dry density of mat'l passing the No. 4 si
z = correction factor based on % of mat'l ret. on No. 4 sieve *(see Table 2 for applicable values)*
c = percent retained on the No. 4 sieve
160 = constant, max. dry dens. of siliceous gravel based on a specific gravity of 2.564
100 = constant, to convert percent to a decimal

TABLE 1 - ENGLISH

Maximum Dry Density of Material Passing the No. 4 Sieve (lb/ft^3) (pr)

Percent Retained on the No. 4 Sieve (c)	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
95.0	97.0	97.4	97.8	98.2	98.6	99.0	99.4	99.9	100.3	100.7	101.2	101.6	102.0	102.5	102.9	103.4
96.0	98.0	98.4	98.8	99.2	99.6	100.0	100.4	100.8	101.3	101.7	102.1	102.6	103.0	103.4	103.9	104.3
97.0	98.9	99.3	99.7	100.2	100.6	101.0	101.4	101.8	102.2	102.7	103.1	103.5	104.0	104.4	104.8	105.3
98.0	99.9	100.3	100.7	101.1	101.5	102.0	102.4	102.8	103.2	103.6	104.0	104.5	104.9	105.3	105.8	106.2
99.0	100.9	101.3	101.7	102.1	102.5	102.9	103.3	103.7	104.2	104.6	105.0	105.4	105.9	106.3	106.7	107.2
100.0	101.9	102.3	102.7	103.1	103.5	103.9	104.3	104.7	105.1	105.5	106.0	106.4	106.8	107.2	107.7	108.1
101.0	102.9	103.3	103.7	104.1	104.5	104.9	105.3	105.7	106.1	106.5	106.9	107.3	107.8	108.2	108.6	109.0
102.0	103.9	104.3	104.7	105.0	105.4	105.8	106.2	106.6	107.0	107.5	107.9	108.3	108.7	109.1	109.5	110.0
103.0	104.9	105.3	105.6	106.0	106.4	106.8	107.2	107.6	108.0	108.4	108.8	109.2	109.6	110.1	110.5	110.9
104.0	105.9	106.2	106.6	107.0	107.4	107.8	108.2	108.6	109.0	109.4	109.8	110.2	110.6	111.0	111.4	111.8
105.0	106.8	107.2	107.6	108.0	108.4	108.7	109.1	109.5	109.9	110.3	110.7	111.1	111.5	111.9	112.3	112.8
106.0	107.8	108.2	108.6	108.9	109.3	109.7	110.1	110.5	110.9	111.3	111.7	112.1	112.5	112.9	113.3	113.7
107.0	108.8	109.2	109.5	109.9	110.3	110.7	111.0	111.4	111.8	112.2	112.6	113.0	113.4	113.8	114.2	114.6
108.0	109.8	110.1	110.5	110.9	111.3	111.6	112.0	112.4	112.8	113.1	113.5	113.9	114.3	114.7	115.1	115.5
109.0	110.8	111.1	111.5	111.9	112.2	112.6	113.0	113.3	113.7	114.1	114.5	114.9	115.2	115.6	116.0	116.4
110.0	111.7	112.1	112.5	112.8	113.2	113.5	113.9	114.3	114.7	115.0	115.4	115.8	116.2	116.6	116.9	117.3
111.0	112.7	113.1	113.4	113.8	114.1	114.5	114.9	115.2	115.6	116.0	116.3	116.7	117.1	117.5	117.9	118.2
112.0	113.7	114.1	114.4	114.8	115.1	115.5	115.8	116.2	116.5	116.9	117.3	117.6	118.0	118.4	118.8	119.1
113.0	114.7	115.0	115.4	115.7	116.1	116.4	116.8	117.1	117.5	117.8	118.2	118.6	118.9	119.3	119.7	120.1
114.0	115.7	116.0	116.3	116.7	117.0	117.4	117.7	118.1	118.4	118.8	119.1	119.5	119.9	120.2	120.6	121.0
115.0	116.6	117.0	117.3	117.6	118.0	118.3	118.7	119.0	119.4	119.7	120.1	120.4	120.8	121.1	121.5	121.9
116.0	117.6	117.9	118.3	118.6	118.9	119.3	119.6	120.0	120.3	120.6	121.0	121.3	121.7	122.0	122.4	122.8
117.0	118.6	118.9	119.2	119.6	119.9	120.2	120.6	120.9	121.2	121.6	121.9	122.3	122.6	122.9	123.3	123.6
118.0	119.6	119.9	120.2	120.5	120.9	121.2	121.5	121.8	122.2	122.5	122.8	123.2	123.5	123.9	124.2	124.5
119.0	120.5	120.9	121.2	121.5	121.8	122.1	122.5	122.8	123.1	123.4	123.8	124.1	124.4	124.8	125.1	125.4
120.0	121.5	121.8	122.1	122.4	122.8	123.1	123.4	123.7	124.0	124.4	124.7	125.0	125.3	125.7	126.0	126.3

TABLE 1: MAXIMUM DRY DENSITY FOR SOILS WITH SILICEOUS GRAVEL ONLY

example:

pr = 109.1
c = 42
z = 0.95

$$PR = \frac{160 \times 109.1 \times 0.95}{\left(\frac{42}{100}\right) \times 109.1 \times 0.95 + 160 \times \left(1 - \frac{42}{100}\right)}$$

$$= \frac{16{,}583.2}{43.530 + 160 - 67.200}$$

$$= \frac{16{,}583.2}{136.330}$$

$$= 121.640$$

$$PR = 121.6$$

Calculate the optimum percent moisture for materials with siliceous gravel retained on the 4.75 sieve in the range of 5 - 60 percent (OM) to the nearest 0.1% using the following formula:

$$OM = \left[\left(\frac{100 - c}{100}\right) \times om\right] + \frac{c}{100}$$

where:

c = material retained on the No. 4 sieve, %
om = opt. moisture of mat'l. passing No. 4 sieve, from the Family of Curves, %
100 = constant

Note A-6: *Equation assumes 1.0 % absorbed moisture in siliceous gravel retained on No. 4 sieve.*

example:

c = 42
om = 16.1 *(from Family of Curves)*

$$OM = \left[\frac{(100 - 42)}{100} \times 16.1\right] + \frac{42}{100}$$

$$= \left[\frac{58}{100} \times 16.1\right] + 0.42$$

$$= [0.58 \times 16.1] + 0.42$$

$$= 9.338 + 0.42$$

$$= 9.758$$

$$OM = 9.8\%$$

VI. Report

A. Maximum Dry Density as PR to the nearest 0.1 lb/cu ft
B. Opt. % Moisture Content as OM, to the nearest 0.1%
C. Family of Curves Zone Number

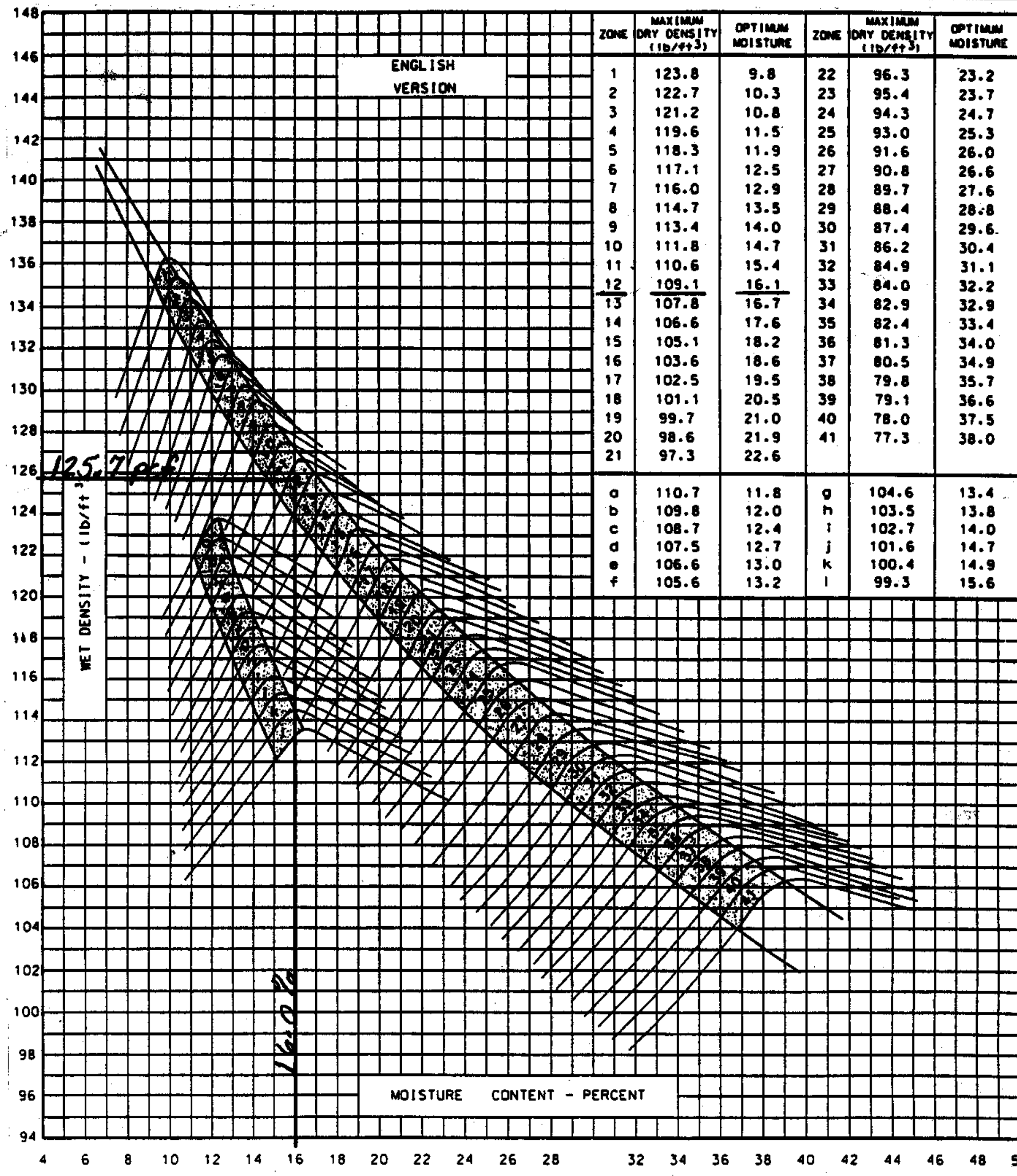
VII. Normal Test Reporting Time

The normal test reporting time is 3 hours.

TABLE 2

Table of Correction Factors
(21 - 60% Siliceous Aggregate Retained on No. 4 Sieve)

(% RETAINED - NO. 4 SIEVE) c	CORRECTION FACTOR z
21 - 25	0.99
26 -30	0.98
31 - 35	0.97
36 - 40	0.96
41 - 45	0.95
46 - 50	0.94
51 -55	0.92
56 -60	0.89



ZONE	MAXIMUM DRY DENSITY (lb/ft³)	OPTIMUM MOISTURE	ZONE	MAXIMUM DRY DENSITY (lb/ft³)	OPTIMUM MOISTURE
1	123.8	9.8	22	96.3	23.2
2	122.7	10.3	23	95.4	23.7
3	121.2	10.8	24	94.3	24.7
4	119.6	11.5	25	93.0	25.3
5	118.3	11.9	26	91.6	26.0
6	117.1	12.5	27	90.8	26.6
7	116.0	12.9	28	89.7	27.6
8	114.7	13.5	29	88.4	28.8
9	113.4	14.0	30	87.4	29.6
10	111.8	14.7	31	86.2	30.4
11	110.6	15.4	32	84.9	31.1
12	109.1	16.1	33	84.0	32.2
13	107.8	16.7	34	82.9	32.9
14	106.6	17.6	35	82.4	33.4
15	105.1	18.2	36	81.3	34.0
16	103.6	18.6	37	80.5	34.9
17	102.5	19.5	38	79.8	35.7
18	101.1	20.5	39	79.1	36.6
19	99.7	21.0	40	78.0	37.5
20	98.6	21.9	41	77.3	38.0
21	97.3	22.6			
a	110.7	11.8	g	104.6	13.4
b	109.8	12.0	h	103.5	13.8
c	108.7	12.4	i	102.7	14.0
d	107.5	12.7	j	101.6	14.7
e	106.6	13.0	k	100.4	14.9
f	105.6	13.2	l	99.3	15.6

FAMILY OF MOISTURE-DENSITY CURVES - ENGLISH

For use with DOTD TR 415, Method A

Figure A-1 (English)
Family of Moisture-Density Curves - (03-22-4050)

MATT MENU SELECTION - 07

Louisiana Department of Transportation and Development
DENSITY & MOISTURE CONTENT WORK SHEET

DOTD 03-22- 0750
Metric/ English
Rev. 9/98

Metric/English (M or E) E *(Entry Field Located on Menu)*

Project No. ____ **Date Tested** ____ **Material Code** ____
Submitted By ____ **Purpose Code** ____ **Spec. Code** ____
Test Method ____ *N = Nuclear S = Sand Cone* **Item Number** ____
Station Tested ____ + ____ **Section & Test No.** ____

Location: ____ Lift No: ____ Depth of Test: ____

OM:	Optimum % Moisture Content of Total Material (TR 415 or TR 418)	OM	9.8
%FM:	Field % Moisture Content at Compaction (TR 403) *(See back for calculations)*	%FM	
P_1:	% Pulverization 19mm (3/4" SIEVE) (TR 431) *(See back for calculations)*	P_1	
P_2:	% Pulverization 4.75mm (NO.4 SIEVE) (TR 431) *(See back for calculations)*	P_2	

Max. Dry Density Method 1
(1 = TR 415 A 2 = TR 415 B 3 = TR 418)

(TR 415) Cross Reference Test No.	Sta. No.:		
a: Total Wet Mass (Wt.) of Sample	15.64		
b: Mass (Wt.) of +4.75 (+4) Material	6.54		
c: % By Mass (Wt.) of 4.75 (+4)Retained (100 b/a)	42		
d: Mass (Wt.) of Mold & Soil	13.51		
e: Mass (Wt.) of Mold	9.32		
f: Mass (Wt.) of Compacted Soil (d - e)	4.19		
g: Wet Density (f / 0.944) or (f / 2.832) or (f / 2.124) or (f x 30) or (f x 10) or (f / 0.075)	125.7		
h: Mass (Wt.) of Wet Soil	1.38		
i: Mass (Wt.) of Dry Soil	1.19		
j: Mass (Wt.) of Water (h - i)	0.19		
k: % Moisture Content (100 j/i) (TR 403)	16.0		
l: Dry Density 100g / (100 + k)			

om (from Family of Curves): 16.1 *pr (from Family of Curves):* 109.1 FAMILY OF CURVES ZONE NUMBER 12

SAND METHOD (TR 401)

SA: Mass (Wt.) of Sand in Mold	
SB: Vol. of Mold	
SC: Unit Mass (Wt.) of Sand (SA/SB)	
SD: Orig. Mass (Wt.) of Sand	
SE: Final Mass (Wt.) of Sand	
SF: Mass (Wt.) of Sand in Cone (SD-SE)	
SG: Orig. Mass (Wt.) of Sand	
SH: Final Mass (Wt.) of Sand	
SI: Mass (Wt) of Sand in Cone & Hole (SG-SH)	
SJ: Mass (Wt.) of Sand in Hole (SI-SF)	
SV: Vol. of Hole (SJ/SC)	
SW: Dry Mass (Wt.) of Material	
SDD: Dry Density (SW / SV)	
PR: Maximum Dry Dens. (TR 415 / TR 418)	
%PR: % Density (Sand) (SDD / PR) x 100	

NUCLEAR METHOD (TR 401)

Nuclear Device No.	Test 1	Test 2	Test 3
DS: Density Standard Count			
DC: Density Test Count			
DR: Density Count Ratio (DC / DS)			
WD: Wet Density			
MS: Moisture Standard Count			
MC: Moisture Test Count			
MR: Moisture Count Ratio (MC / MS)			
M: Moisture by Mass (Wt.)			
MP: Moisture by Percent - *TR 401* ☐ / *TR 403* ☐			
NDD: Dry Density (WD - M) or $\frac{100 \times WD}{100 + MP}$			
%NPR: % Density (NDD / PR) x 100			
ADD: Average Dry Density (NDD) or (NDD/3)			
PR: Maximum Dry Density (TR 415 TR 418)	121.6		
%PR: % Dens.(Nuclear) (% NPR) or (% NPR/3)			

Remarks ____

Inspector ____ (Nuclear Film Badge No.) ____ *(Signature)*

Figure A-2 (English)
Density & Moisture Content Worksheet - Front (03-22-0750)

Pulverization, P_1 and P_2 (TR 431)					
* Test No. * *Utilize as many columns as necessary per test section.*		1	2	3	4
Adjusted Wet Mass (Wt) Sample (A)					
Mass (Wt) of + 19 mm (3/4 in) Material (B_1)					
Mass (Wt) of + 4.75 mm (No. 4) Material (B_2)					
% Pulverization 19 mm (3/4 in) (P_1)	$100 \times \frac{(A - B_1)}{A}$				
% Pulverization 4.75 mm (No. 4) (P_2)	$100 \times \frac{A - (B_1 + B_2)}{A}$				

Field Moisture Content at Compaction, % FM (TR 403)					
* Test No. * *Utilize as many columns as necessary per test section.*		1	2	3	4
Total Wet Mass (Wt) of Matl. at Compaction (A)					
Total Dry Mass (Wt) of Matl. at Compaction (B)					
Mass (Wt) of Water (C)	(A - B)				
% Field Moisture Content (% FM)	$100 \times \frac{C}{B}$				

Optimum Moisture and Maximum Dry Density Adjustments for Material Containing 20% - 60 % Siliceous Aggregate (TR 415)				
		1	2	3
Optimum % Moist. of Tot. Material, (OM)	$OM = [(\frac{100 - c}{100}) \times om] + \frac{c}{100}$	9.8		
Maximum Dry Density, lb/ft³ (PR) *(English)*	$PR = \frac{160 \times pr \times z}{\frac{c}{100} \times pr \times z + [160 \times (1 - \frac{c}{100})]}$	121.6		
Maximum Dry Density, kg/m³ (PR) *(Metric)*	$PR = \frac{2564 \times pr \times z}{\frac{c}{100} \times pr \times z + [2564 \times (1 - \frac{c}{100})]}$			

Figure A-2 (English)
Density & Moisture Content Worksheet - Back (03-22-0750)

Method of Test
FIELD MOISTURE - DENSITY RELATIONSHIPS
DOTD Designation: TR 415 - 99
ENGLISH

METHOD B - DETERMINATION BY FIELD CURVE

I. Scope

A. This test procedure is designed to determine the optimum moisture and maximum dry density of material based on a curve developed from field-condition material. The procedure is applicable to all soils and soil aggregates with or without cement or lime additive, including recycled in-place material. This method is to be used as permitted by DOTD TR 418 or the specifications.

Note B-1: *If the moisture contents are properly adjusted during the test to provide a minimum of one point on the wet side and two points on the dry side, maximum density and optimum moisture can be determined with three points by using the Zero Air Voids Line to establish the wet leg of the curve. Additional points will be necessary if the first three moisture contents do not result in two points on the dry side and one point on the wet.*

B. Reference Documents
1. TR 418 - Moisture-Density Relationships
2. TR 403 - Determination of Moisture Content
3. AASHTO M 92 - Wire Cloth Sieves for Testing Purposes
4. DOTD S 401 - Sampling Soils
5. DOTD TR 108 - Splitting and Quartering Samples

II. Apparatus

A. **Mold**
1. A cylindrical metal mold having a capacity of 1/30 ft^3 manufactured with an internal diameter of 4.000 ±0.016 in. and a height of 4.584 ±0.005 in. and with a detachable collar approximately 2.5 in. in height, which can be fastened firmly to a base plate.
2. Molds are to be replaced when any diameter is more than 4.024 in. or the height is less than 4.550 in. at any point.
3. A cylindrical metal mold, having a capacity of 1/10 ft^3, manufactured with an internal diameter of 6.000±0.026 in. and a height of 6.100±0.016 in., and with a detachable collar approximately 3.5 in. in height, which can be fastened firmly to a base plate.
4. Molds shall be replaced if any diameter is more than 6.039 in. or the height is less than 6.000 in. at any point.
5. A cylindrical metal mold, having a capacity of 0.075 (1/13.33) ft^3, manufactured with an internal diameter of 6.000±0.0026 in. and a height of 4.584 ±0.0005 in., and with a detachable collar approximately 2.5 in. in height, which can be fastened firmly to a base plate.
6. Molds shall be replaced if any diameter is more than 6.039 in. or the height is less than 4.550 in. at any point.

Note B-2: *Different makes of compactive devices may use mold base plates of different designs. The mold base plate must be compatible with the make of the compactive device used.*

B. **Compactive device**
1. A metal 5.50 ±0.05 lb rammer with a circular striking face with a diameter of 2.00 ±0.01 in. and arranged to control the height of drop to 12.00 ±0.06 in..
2 A metal 10.0 ±0.1 lb rammer, with a circular striking face with a diameter of 2.00±0.01 in. and arranged to control the height of drop to 18.00±0.06 in. (for use with 1/10 ft^3 mold only).

C. **Compaction block** - A uniform rigid foundation such as a stable block or pedestal composed of portland cement concrete with a smooth, level surface on the top and bottom, with both surfaces parallel, weighing a minimum of 200 lbs. The compaction block may be obtained from the district laboratory.

D. **Sraightedge** - steel straightedge, approximately 12 in. long.

E. **Balance or scale** - a balance having a capacity of 30 lb or more and sensitive to 0.01 lb

F. **Sieve** - a No. 4 sieve conforming to AASHTO Designation M 92

G. **Tools**
1. **Mixing pans** - with appropriate covers
2. **Shovel**
3. **Spoons**
4. **Pointed trowel**
5. **Spatula** - or large suitable mechanical device for thoroughly mixing the soil with water
6. **Large screwdriver** - to remove material from mold
7. **Graduated cylinder** (optional)
8. **Scalping screen** - 1 in. brass sieve or box screen

H. **Water**
I. **Sealable Containers** - capable of holding required quantity of material (e.g., gallon cans with friction top lids)
J. **Laboratory Curve**
K. **Density and Moisture Content Worksheet** - Form No. 03-22-0750 (Figure B-1)
L. **Field Compaction Curve** - Form No. 03-22-4193 (Figure B-2)
M. **Engineer's Curve** - Alvin 1010-21 or equivalent

III. Sample: *Processed material in field condition.*

A. When the aggregate retained on the No. 4 sieve is 5% or greater, obtain a representative sample of 75 lb of material in accordance with S-401. Obtain the sample from the roadway after blending of soil and additive (if applicable) prior to compaction.
B. When the aggregate retained on the No. 4 sieve is less than 5%, obtain a representative sample of 30 lb of material in accordance with S-401. Obtain the sample from the roadway after blending of soil and additive (if applicable) prior to compaction.
C. Thoroughly mix the material.
D. In accordance with TR 108, split the mixed sample into five reasonably equal sized representative portions. Seal the representative portions in separate containers that will prevent moisture loss.

IV. Procedure

A. Select one of the representative portions. Squeeze a handful of material in the palm of your hand and analyze the moisture content in terms of the following.
   1. Material forms a cake which will bear very careful handling without breaking - material is at least 3 - 5% below optimum moisture.
   2. Material just dampens the hand when squeezed - material is near or at optimum moisture.
   3. Material leaves visible moisture on the hand when squeezed - material is above optimum moisture. For the purpose of this test, the material should be approximately 2 - 3% above optimum.
B. Adjust the moisture content of the representative portions until three portions meet each of the moisture conditions shown in Steps A. 1 - 3, using the following methods. Reseal each portion in its container. Set the remaining portions aside.
   1. Air - drying - Spread the representative portion into a pan and stir it as often as possible during the drying period.

Note B-3: *Under some weather conditions (e.g., low temperature, high humidity), it may be necessary to use the procedure for drying material in TR 403 to dry the material to a suitable moisture content. If this method is used, take care not to dry the material beyond the point needed to perform this test. Do not dry to constant weight.*

   2. Increase moisture content - Place a representative portion into another pan. Determine the weight of the representative portion. In accordance with **Step V. A.**, calculate the amount of water required to increase the moisture content of the material approximately 2 - 3%. Add sufficient water to increase the moisture content of the material in increments of approximately 2 - 3%.

Note B-4: *The actual quantity of water needed will depend on the gradation and initial moisture content of the representative portion.*

C. Select the correct size mold.
   1. If the percent retained on No. 4 sieve is less than 5, select the 1/30 ft^3 mold.
   2. If the percent retained on the No. 4 sieve is 5 or greater, select the 1/10 ft^3 or the 0.075 ft^3 mold.
D. Mold the representative portions.
   1. Attach base plate to mold. Weigh mold and base plate to the nearest 0.01 lb and record as **e** on the worksheet.
   2. Attach the collar to the mold to complete the mold assembly and place the mold on the compaction block.
   3. Open the container of one representative portion and thoroughly mix the material.
   4. Place a quantity of the material in the mold in an even layer that will yield slightly more than 1/3 the volume of the mold after compaction. Remove and discard any material larger than one in. in diameter (e.g., aggregate, RAP, clumps of previously stabilized materials), and any trash (e.g., bottle caps, pavement markers, pieces of concrete, steel, etc.). Reseal the container.
   5. Use a pointed trowel to rearrange particles, filling voids in the loose material without compacting the material, to a uniform lift thickness.
   6. Rest the rammer on top of the layer to be compacted. Compact the layer.
      a. When using the 1/30 ft^3 mold, use 25 blows per layer with the 5.50 lb rammer from a 12 in. drop.

b. When using the 1/10 ft^3 mold, use 75 blows per layer with the 5.50 lb rammer from a 12 in. drop or 28 blows per layer with the 10.0-lb rammer from an 18 in. drop.
c. When using the 0.075 ft^3 mold, use 56 blows per layer with the 5.50 lb rammer from a 12 in. drop or 20 blows per layer with the 10.0-lb rammer from an 18 in. drop.

7. Note the height of the compacted material. If the compacted layer is not 1/3 the height of the mold, correct for any deviation by adjusting the quantity of material used for the subsequent layer.
8. Repeat **Steps IV. D. 1 - 7** for two more layers.
9. After the third layer has been compacted, place the mold assembly and compacted specimen in a pan.
10. Tap the collar with the straightedge to loosen material bond. Remove the collar from the mold, without twisting or causing shear stress to the molded specimen.
11. Note the height of the compacted test specimen.
    a. If the compacted material is greater than 0.25 in. above the top of the mold (for the 1/30 ft^3 mold) or 0.5 in. (for the 1/10 or 0.075 ft^3 mold), remix it with the original material and repeat the test.
    b. If the compacted material is below the rim of the mold, remove all the material from the mold, remix it with the original material and repeat the test.
12. Keeping the mold, base plate, and specimen in the pan, trim the specimen even with the top of the mold, using the straightedge. Fill any depressions formed during trimming with the trimmed material. After the depressions are filled, smooth the top of the cylinder with the straightedge even with the top of the mold.
13. Determine the weight of the mold, base plate, and specimen and record as **d** on the worksheet.
14. Determine the wet density of the specimen in accordance with **Step V.B**. Record as **g** on the worksheet.
15. Detach the base plate from the mold. Remove the specimen from the mold.
16. Take a moisture sample from the center of the compacted specimen. Determine the wet weight, dry weight, weight of water, and moisture content of the test specimen in accordance with DOTD TR 403. Record on the worksheet as **h**, **i**, **j**, and **k** (respectively).
17. Determine the dry density of each specimen in accordance with **Step V.C.**
18. Plot the point on the Field Compaction Curve, representing the intersection of a horizontal line projected from the dry densities and a vertical line projected from the moisture contents.
19. Open the container for the second representative portion and thoroughly mix the material.
20. Mold this material in accordance with **Steps D. 1 - 18.**
21. Thoroughly mix the third representative portion. Mold this material in accordance with **Steps D. 1 - 16.**

E. Develop a moisture-density curve.
1. Draw a line parallel to the Zero Air Voids Line through the point with the highest moisture content.
2. Draw a line through the other two points, intersecting the line drawn in **Step 1.**
3. Evaluate the two lines in terms of the following
    a. Ensure that a minimum of three points meet the conditions in **Step IV. A**.
    b. No point falls to the right of the Zero Air Voids Line. Any point that falls to the right of the Zero Air Voids Line is not valid and must be rerun.
4. If the above conditions are met, round the peak of the curve, as closely as possible to the intersection, to form a smooth continuous line.
5. If all above conditions are not met, run additional representative portions in accordance with **Steps IV.D.1 - 18** until these conditions are met.
6. Determine the Optimum Moisture Content, %. The Optimum Moisture Content is the moisture content corresponding to the peak of the Dry Weight Density Curve.
7. Determine the Maximum Dry Density. The Maximum Dry Density is the dry density of the soil at the optimum moisture content.

V. Calculations

A. Use the following formula to calculate the quantity of water needed to increase the moisture content of the representative portion by approximately 2 - 3%, as needed.

$$C = A \times B$$

where:

C = approximate quantity of water to be added, lb
A = wet wt of representative portion, lb
B = water to be added, decimal

example:

A = 5 lb
B = 0.02

$$C = 5 \times 0.02$$

$$C = 0.1 \text{ lb}$$

Note B-5: *If the technician prefers to measure water, instead of weighing it, to convert from weight to volume in mL, multiply water weight by the constant 454 (the number of grams in a pound) [1 g = 1 mL].*

Example: 0.1 lb x 454 = 45.4 mL

B. Calculate the wet density of each test specimen.

1. Calculate the wet weight of compacted soil to the nearest 0.01 lb using the following formula:

$$f = d - e$$

where:

f = wet wt of compacted soil
d = wt of mold, base plate, and specimen, lb
e = wt of mold and base plate

example:

d = 13.51 lb
e = 9.32 lb

$$f = 13.51 - 9.32$$

$$f = 4.19 \text{ lb}$$

2. Calculate the wet density of each specimen to the nearest 0.1 lb/ft^3 using the following formulas:

For the 1/30 ft^3 mold: $g = f \times 30$
For the 1/10 ft^3 mold: $g = f \times 10$
For the 0.075 ft^3 mold: $g = f \div 0.075$

where:

g = wet density of the specimen
f = wet wt of compacted soil, lb
30 and 10 = constants, representing the reciprocal of the volumes of the molds, ft^3

example:

f = 4.19

$$g = 4.19 \times 30$$
$$g = 125.7 \text{ lb/ft}^3$$

C. Calculate the dry density to the nearest 0.1 lb/ft^3 using the following formula:

$$I = \frac{100 \times g}{100 + k}$$

where:

I = dry density, lb/ft^3
g = wet density of specimen, lb/ft^3
k = moisture content, %
100 = constant, converts to decimals

example:

g = 125.7
k = 15.2

$$I = \frac{100 \times 125.7}{100 + 15.2}$$

$$\frac{12{,}570}{115.2}$$

$$I = 109.114 = 109.1$$

VI. Report

Report optimum moisture (OM) and maximum dry density (PR).

VII. Normal Test Reporting Time

Normal testing and reporting time is two hours.

MATT MENU SELECTION - 07

Louisiana Department of Transportation and Development
DENSITY & MOISTURE CONTENT WORK SHEET

DOTD 03-22- 0750
Metric/ English
Rev. 9/98

Metric/English (M or E) E *(Entry Field Located on Menu)*

Project No. ____ **Date Tested** ____ **Material Code** ____
Submitted By ____ **Purpose Code** ____ **Spec. Code** ____
Test Method ____ *N = Nuclear S = Sand Cone* **Item Number** ____
Station Tested ____ + ____ **Section & Test No.** ____

Location: ____ Lift No: ____ Depth of Test: ____

OM:	Optimum % Moisture Content of Total Material (TR 415 or TR 418)	OM	16.1
%FM:	Field % Moisture Content at Compaction (TR 403) *(See back for calculations)*	%FM	
P_1:	% Pulverization 19mm (3/4" SIEVE) (TR 431) *(See back for calculations)*	P_1	
P_2:	% Pulverization 4.75mm (NO.4 SIEVE) (TR 431) *(See back for calculations)*	P_2	

(TR 415) Cross Reference Test No. Sta. No.: **Max. Dry Density Method** 2
(1 = TR 415 A 2 = TR 415 B 3 = TR 418)

a: Total Wet Mass (Wt.) of Sample			
b: Mass (Wt.) of +4.75 (+4) Material			
c: % By Mass (Wt.) of 4.75 (+4)Retained (100 b/a)			
d: Mass (Wt.) of Mold & Soil	13.51	13.34	13.51
e: Mass (Wt.) of Mold	9.32	9.33	9.32
f: Mass (Wt.) of Compacted Soil (d - e)	4.19	4.01	4.19
g: Wet Density (f / 0.944) or (f / 2.832) or (f / 2.124) (f x 30) or (f x 10) or (f / 0.075)	125.7	120.3	125.7
h: Mass (Wt.) of Wet Soil	1.44	1.39	1.40
i: Mass (Wt.) of Dry Soil	1.25	1.23	1.18
j: Mass (Wt.) of Water (h - i)	0.19	0.16	0.22
k: % Moisture Content (100 j/i) (TR 403)	15.2	13.0	18.6
l: Dry Density 100g / (100 + k)	109.1	106.5	106.0

om *(from Family of Curves)*: ____ pr *(from Family of Curves)*: ____ FAMILY OF CURVES ZONE NUMBER ____

SAND METHOD (TR 401)	
SA: Mass (Wt.) of Sand in Mold	
SB: Vol. of Mold	
SC: Unit Mass (Wt.) of Sand (SA/SB)	
SD: Orig. Mass (Wt.) of Sand	
SE: Final Mass (Wt.) of Sand	
SF: Mass (Wt.) of Sand in Cone (SD-SE)	
SG: Orig. Mass (Wt.) of Sand	
SH: Final Mass (Wt.) of Sand	
SI: Mass (Wt) of Sand in Cone & Hole (SG-SH)	
SJ: Mass (Wt.) of Sand in Hole (SI-SF)	
SV: Vol. of Hole (SJ/SC)	
SW: Dry Mass (Wt.) of Material	
SDD: Dry Density (SW / SV)	
PR: Maximum Dry Dens. (TR 415 / TR 418)	
%PR: % Density (Sand) (SDD / PR) x 100	

NUCLEAR METHOD (TR 401) Nuclear Device No. ____	Test 1	Test 2	Test 3
DS: Density Standard Count			
DC: Density Test Count			
DR: Density Count Ratio (DC / DS)			
WD: Wet Density			
MS: Moisture Standard Count			
MC: Moisture Test Count			
MR: Moisture Count Ratio (MC / MS)			
M: Moisture by Mass (Wt.)			
MP: Moisture by Percent - *TR 401* ☐ / *TR 403* ☐			
NDD: Dry Density (WD - M) or $\frac{100 \times WD}{100 + MP}$			
%NPR: % Density (NDD / PR) x 100			
ADD: Average Dry Density (NDD) or (NDD/3)			
PR: Maximum Dry Density (TR 415 TR 418)	109.8		
%PR: % Dens.(Nuclear) (% NPR) or (% NPR/3)			

Remarks ____

Inspector ____ (Nuclear Film Badge No.) ____ *(Signature)*

Figure B-1 (English)
Density & Moisture Content Worksheet (03-22-0750)

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

DOTD 03-22-4193
English
8/98

DOTD TR 415 METHOD B - ENGLISH

FIELD COMPACTION CURVE

Project No: ______________________ Station No: ______________________

Sample No: ______________________ Date: ______________________

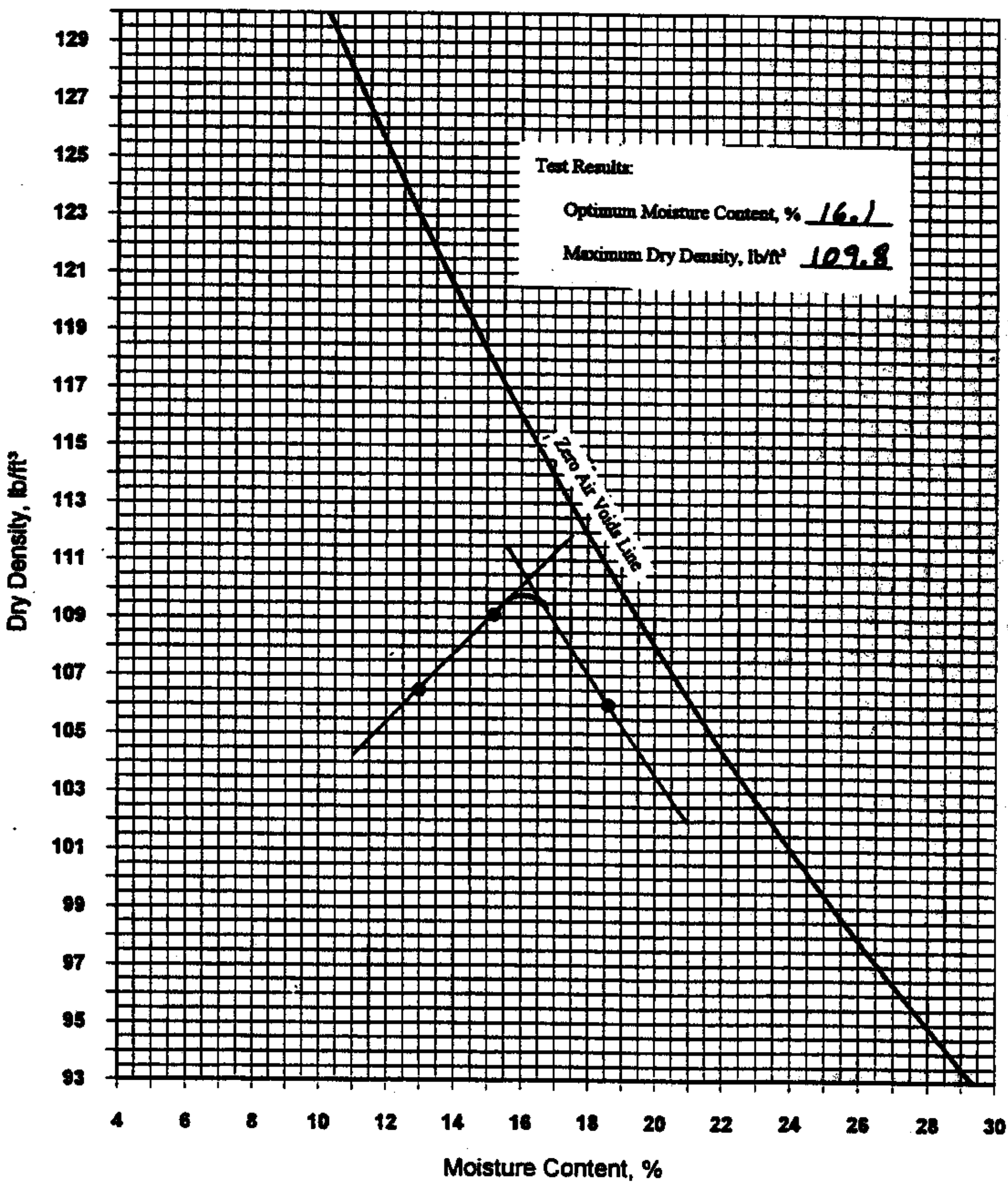


Figure B - 2 (English)
Field Compaction Curve (03-22-4193)